

# **Robotics for law enforcement: Applications beyond explosive ordnance disposal**

Hoa G. Nguyen\* and John P. Bott

Space and Naval Warfare Systems Center  
San Diego, CA 92152 USA

## **ABSTRACT**

We conducted a web-based survey to establish law enforcement robotics needs for applications that extend beyond explosive ordnance disposal. The survey addressed scenarios and tasks where a robot would be used if available, and the tools, features and parameters deemed most important to carry out those tasks. We present in this paper the results of the survey and summarize current robotics research and development efforts by various segments of the Department of Defense that could potentially help meet those law enforcement needs. We also provide a recommended course of action to the Department of Justice for the development of these robotics capabilities.

**Keywords:** Robotics, mobile tele-operated robots, law enforcement, military, survey.

## **1. BACKGROUND**

The field of mobile robotics has matured quickly in the past decade, with more and more robots entering practical field service. The two most active application areas for mobile robots so far have been military and law enforcement. For law enforcement, most robotic activities to date have been in the area of explosive ordnance disposal (EOD), where robots are used to keep the human bomb disposal expert out of harm's way. In 1999, the National Institute of Justice (NIJ) funded the Battelle Memorial Institute to perform a survey on the desired attributes of an EOD robot.<sup>1</sup> In addition, NIJ funded the Space and Naval Warfare Systems Center, San Diego (SSC San Diego), to assess law enforcement needs for robots beyond EOD and identify technologies from Department of Defense robotics projects that can help meet those needs. This paper summarizes the results of that effort. A more detailed report is available from SSC San Diego.<sup>2</sup>

## **2. LAW ENFORCEMENT NEEDS**

### **2.1 Survey Procedure**

To establish law enforcement needs for non-EOD robots, we developed a questionnaire in early May 2000. We then met with members of the Los Angeles Sheriff Department's Special Enforcement Bureau (LASD-SEB) to discuss this questionnaire. From the feedback we received, we decided to convert this questionnaire into a web-based survey, with most questions answerable in the form of radio buttons and check boxes, facilitating the response process.

We let the web-based survey run for 8 weeks, hosted on our SSC San Diego Robotics web site.<sup>3</sup> The survey was publicized by electronic mail to over 200 state and local law enforcement agencies whose e-mail addresses were found at various law-enforcement web sites.<sup>4-7</sup> The National Tactical Officers Association also posted a link to our survey on their web site.<sup>8</sup>

---

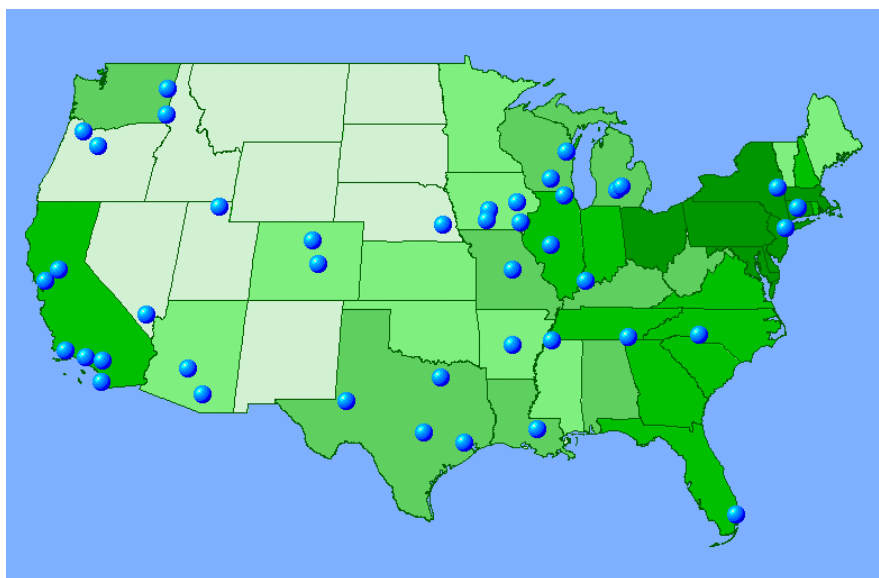
\* E-mail: nguyenh@spawar.navy.mil

Responses coming in were converted by a Perl-script program residing on the web server to text messages and forwarded to another computer for storage. When the survey was completed, a C program combed through the stored messages, tallied up the responses to each question and generated summary tables. These tables were then entered into an Excel spreadsheet, which generated the charts included in this report. The individual messages were also printed out and examined by hand to extract manually entered information (from the “other information” or “notes” and “comments” fields), and to gain insight into unusual answers or unexpected groupings.

The survey has five parts. Part 1 establishes the respondent’s background. We were interested in knowing how a respondent’s familiarity with law-enforcement robots correlates with the actual responses. This hopefully will help us separate long-term desires and goals from more practical, short-term needs as would be reflected in the responses from those with more experience with robots. Part 2 delves into the scenarios where robots would be used, the tasks they would be asked to perform, and the tools required to accomplish those tasks. Part 3 deals with the features and parameters deemed important on the corresponding robots, and part 4 solicits experiences with currently available robots. Part 5 is a short question to establish the law-enforcement community’s interests in various types of mobile robots. A copy of the actual survey questionnaire and tabulated answers is available in our more comprehensive technical report.<sup>2</sup>

## 2.2 Survey Results

We received a total of 65 responses from our web survey, from various localities across the United States, as shown in Figure 1, superimposed on a US population density map.

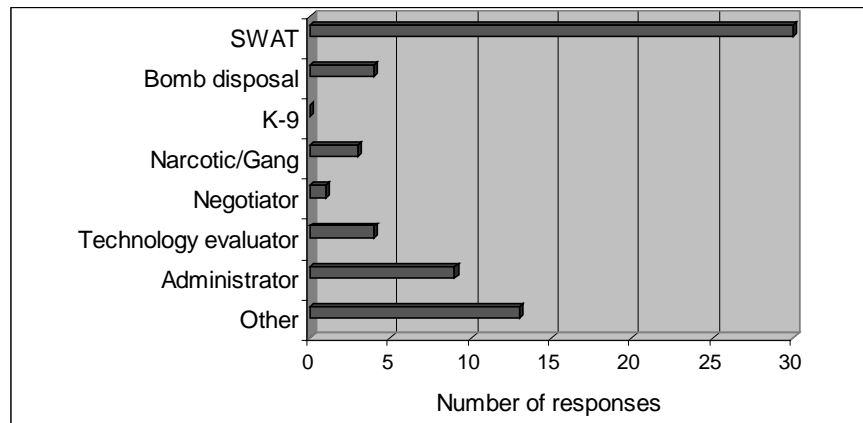


**Figure 1.** Geographic origin of survey responses.

Below is a summary of selected survey answers presented in chart form to facilitate visualization of comparative significance.

### Specialties:

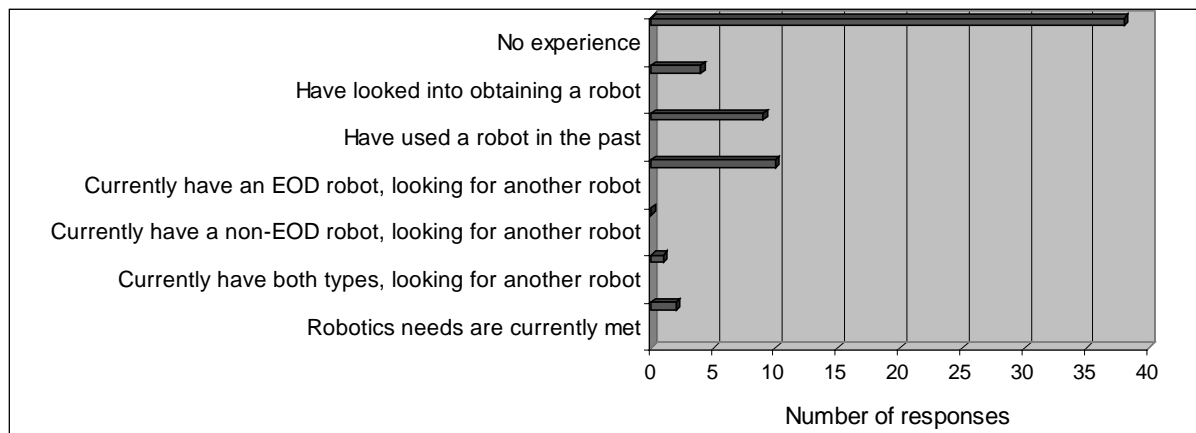
Almost half of the respondents were members of the tactical community. Figure 2 shows the specialties indicated on the survey returns.



**Figure 2.** Specialties of respondents.

#### Robotics experience:

Figure 3 summarizes the respondents' experience with robots. Over 50% of the respondents have no experience with robotics. No respondent reported currently having a non-EOD robot only.



**Figure 3.** Robotics experience among respondents.

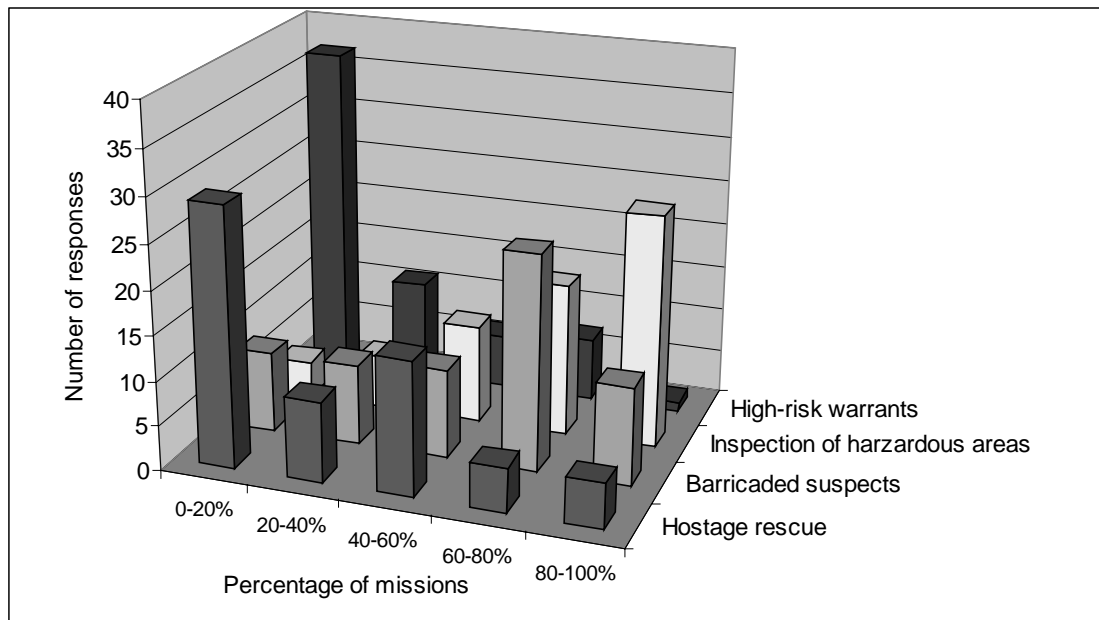
#### Scenarios:

*Inspection of hazardous areas* and *dealing with barricaded suspects* ranked highest on the list of scenarios where a robot would be used if available. *Serving high-risk warrants*, identified during the initial meeting with LASD-SEB, was not deemed appropriate for robotics by most. Figure 4 gives the rating of the four scenarios given in the survey questionnaire. The horizontal axis compartmentalizes the percentages of the missions when a robot would be used if available, and the vertical axis represents the number of survey responses picking those percentages.

Other scenarios that were mentioned include (each by one respondent):

- Reconnaissance in tunnels and storm drains (at US ports of entry)
- Searching for criminals and lost persons
- Acting as hilltop repeater
- Site security
- Public reception and information dispenser

- Remote supervision
- Acting as hostile element in training
- Dealing with suicidal subjects



**Figure 4.** Frequency of robot use (if available) in various scenarios.

#### Tasks:

We listed a number of tasks and questioned the percentage of the times that each task is performed *when a robot, if available, would perform the task*. Figures 5a and 5b summarize the results. For each task, a peak to the right of the graph would indicate that more respondents picked that task as being more important.

We can see from these graphs that the tasks most demanded by respondents for robotics support are *delivery of small items* (wireless telephones, food, etc) and *passive remote communication* (where the target person is not required to cooperate by using a telephone). These are followed by *video, audio surveillance* and *retrieval of small objects*.

Other tasks mentioned (by one respondent each) include:

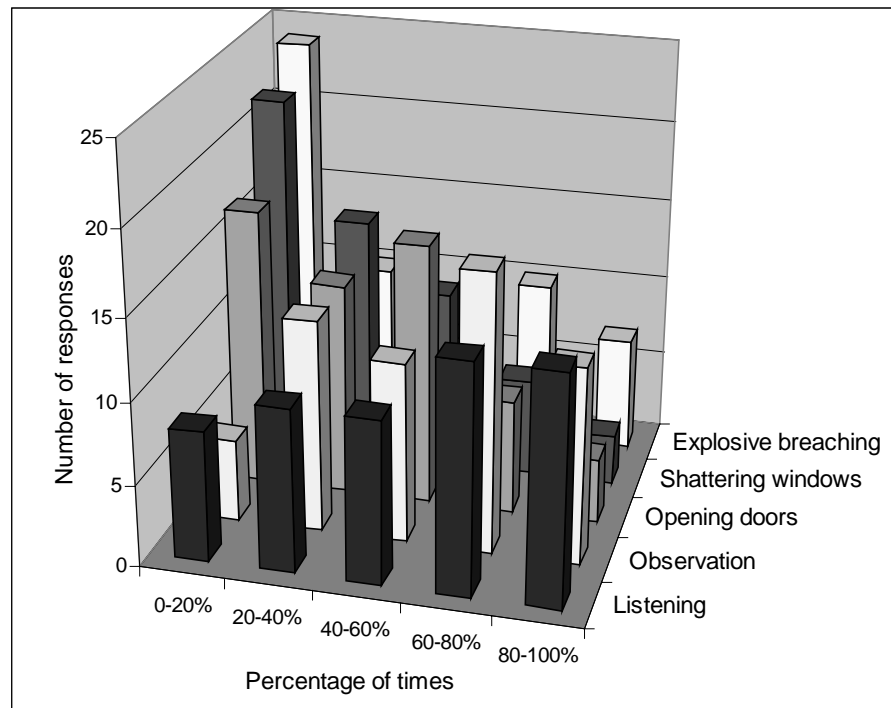
- Creating a diversion
- Providing zone defenses, alerting units when suspects are moving
- Identification of subjects and weapons
- Valve manipulation
- Retrieving injured officer or hostage from hostile environment

#### Tools:

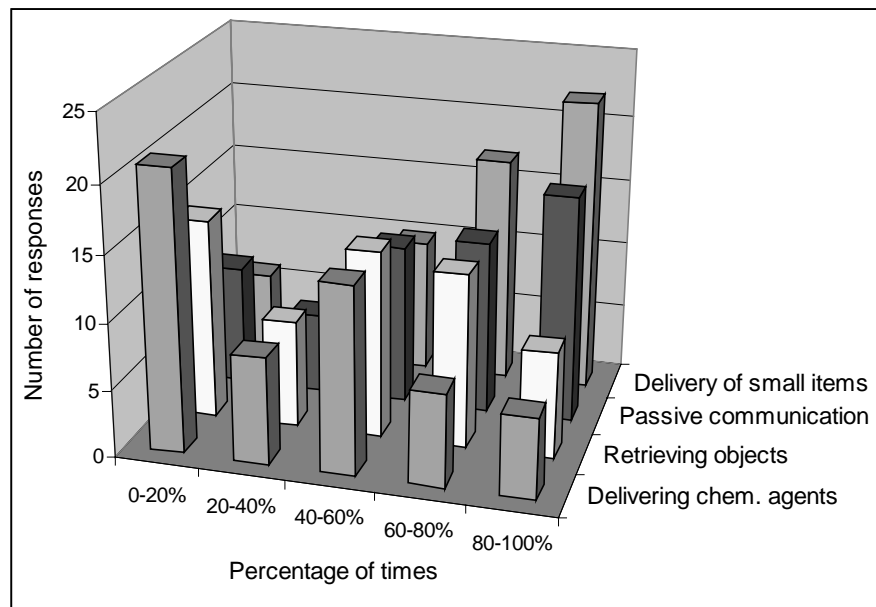
Figures 6 and 7 depict the perceived usefulness of various robot-mounted tools. The frequency that each tool would be used, if available, is listed on the horizontal axis. The vertical axis represents the respondents' selections. The respondents placed emphasis on sensors and effectors, while robot-mounted weapons were deemed not as important. Less-lethal weapons scored somewhat higher than shotguns and grenade launchers. Types of less-lethal weapons mentioned include: beanbag rounds, sage rounds, pepper spray, sting balls, nets, TASER and pulse lighting.

One or more respondents also indicated that law-enforcement robots could use the following tools:

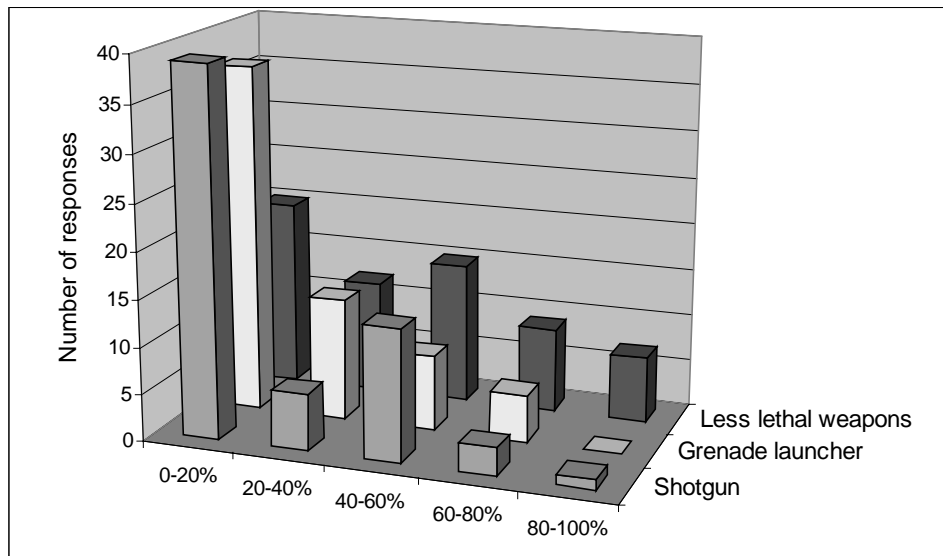
- Tire deflating strips
- Chemical/biological agent sensors
- GPS/dead reckoning locating
- Laser range finder
- Window punch for automobiles



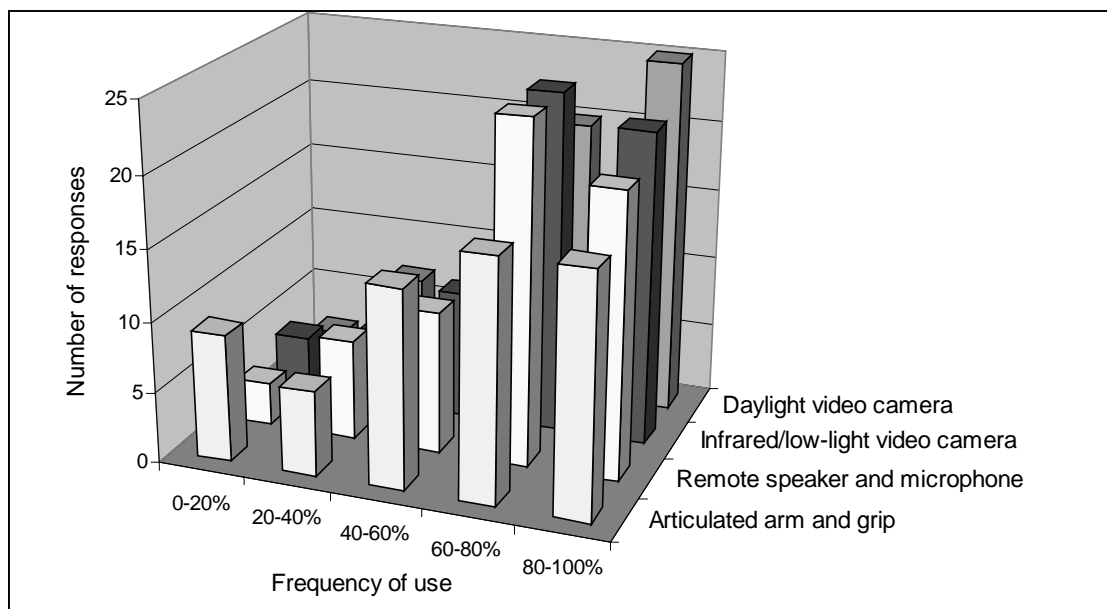
**Figure 5a.** Percentage of times a robot would perform certain tasks.



**Figure 5b.** Percentage of times a robot would perform certain tasks.



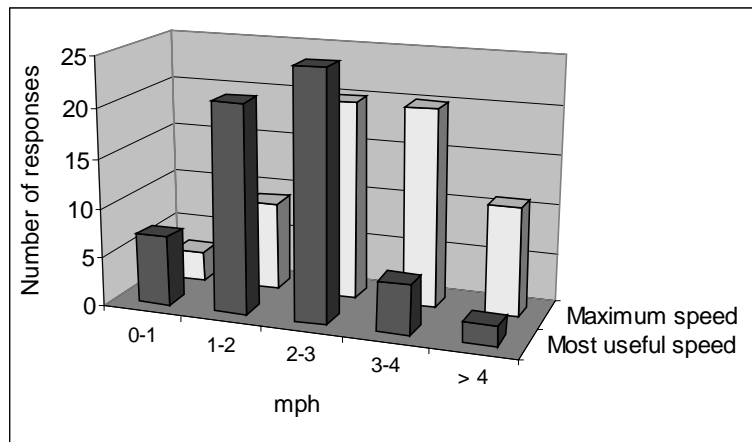
**Figure 6.** Robot-mounted weapons.



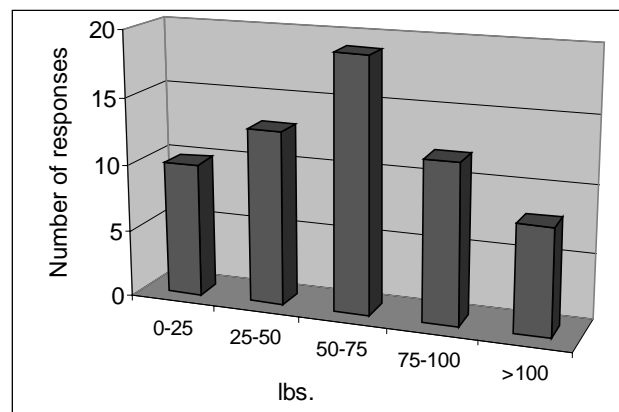
**Figure 7.** Sensors and effectors.

#### Features:

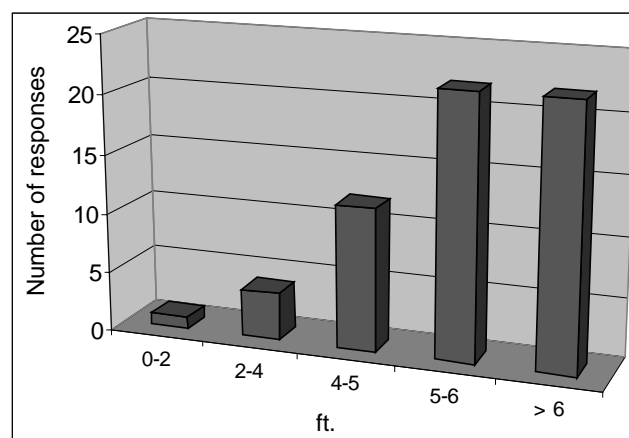
Figures 8 to 14 summarize the responses giving the most reasonable or appropriate values for various features of a robot that would best meet the respondents' needs. While most respondents chose a maximum speed of 2 to 4 miles per hour, the most useful speed was pegged at around 2 miles per hour. The composite most appropriate size for a robot was picked to be 24 to 36" long, 12 to 24" wide, 24 to 36" high (stowed), and weighing 50 to 75 lbs. There is demand for robots smaller than this, but almost no demand for robots larger than 4 feet on each side.



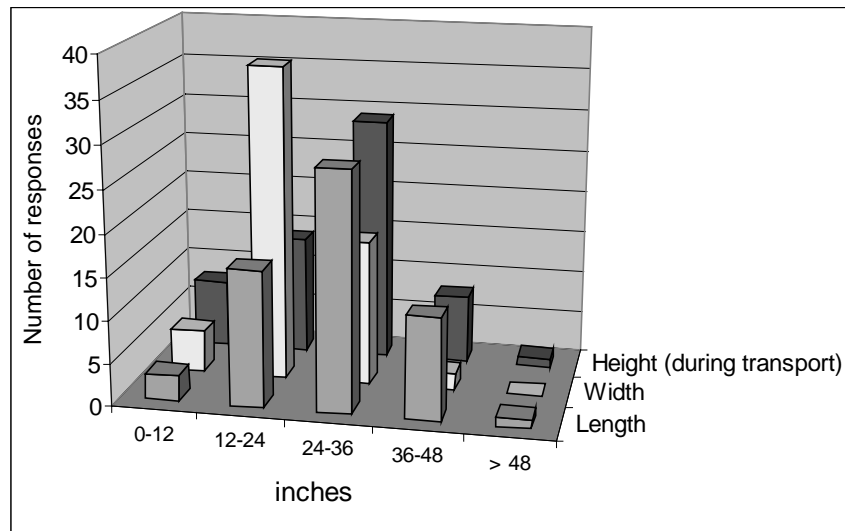
**Figure 8.** Maximum and most useful speeds.



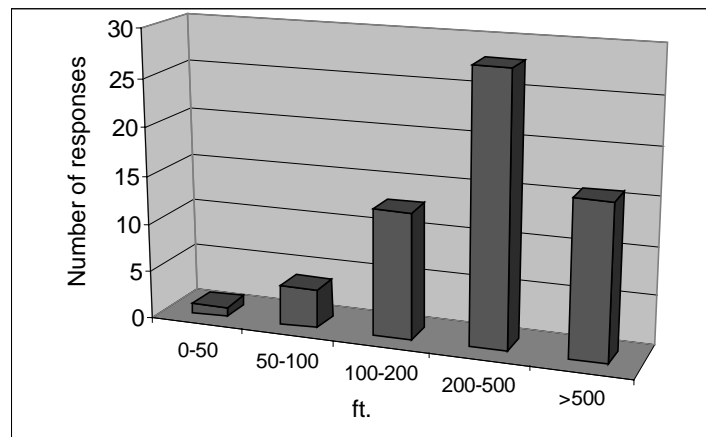
**Figure 9.** Most appropriate weight.



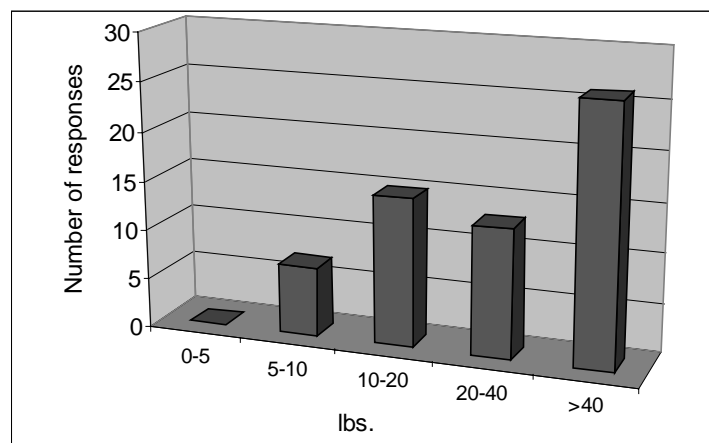
**Figure 10.** Maximum reach.



**Figure 11.** Most appropriate size.

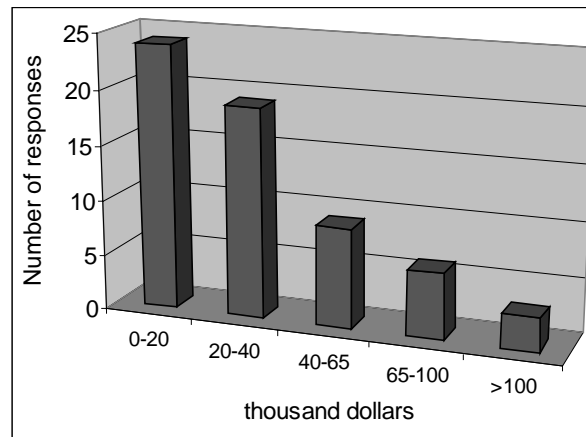


**Figure 12.** Operating/stand-off distance.



**Figure 13.** Manipulator lift capability.

The responses to the question on lift capability were somewhat bimodal. There was desire for robots with maximum lift capability both at around 20 lbs. and at over 40 lbs.

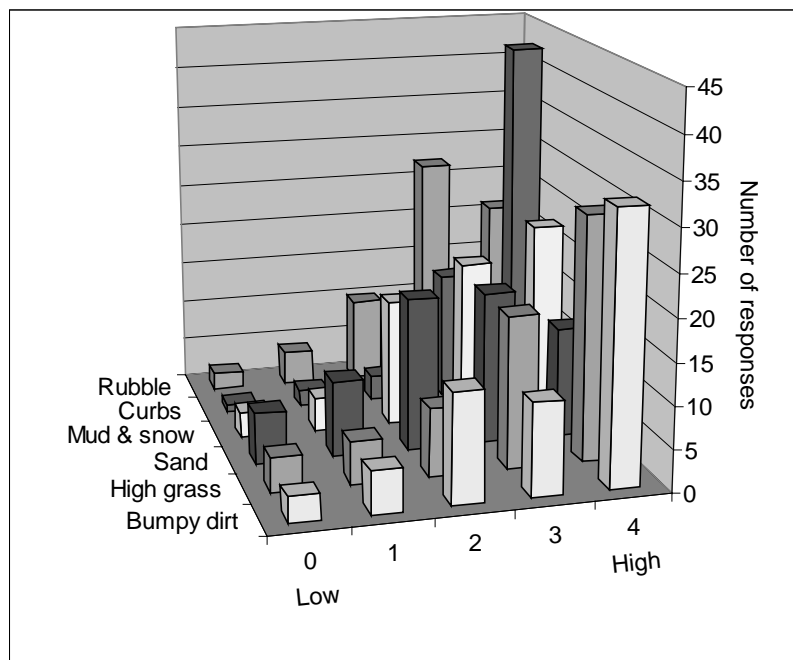


**Figure 14.** Reasonable procurement cost.

A clear majority of the responses picked a reasonable procurement cost of under \$40K. This reflects the limited budgets faced by most local law-enforcement agencies, as singled-out separately by several survey participants.

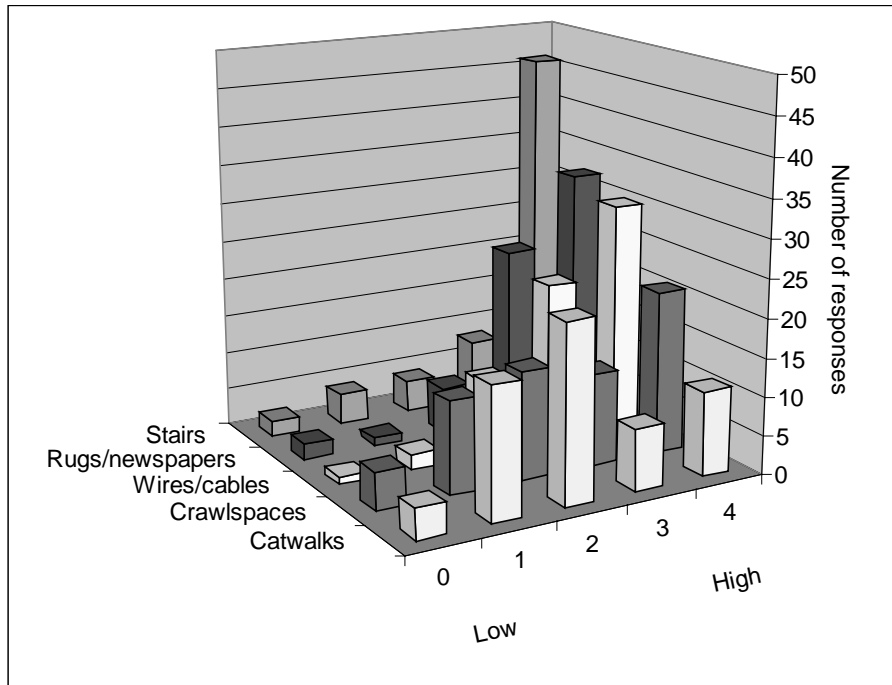
#### Mobility:

Figure 15 summarizes the perceived importance of the robot being able to traverse certain outdoor terrain. On the horizontal axis, 4 is most important, 0 is least. The number of responses is given on the vertical axis for each terrain. From this figure, we can see a heavy emphasis on being able to traverse over curbs, bumpy dirt, and high grass, followed by mud, snow and rubble. Sand received the least emphasis.



**Figure 15.** Importance of being able to traverse various outdoor terrain.

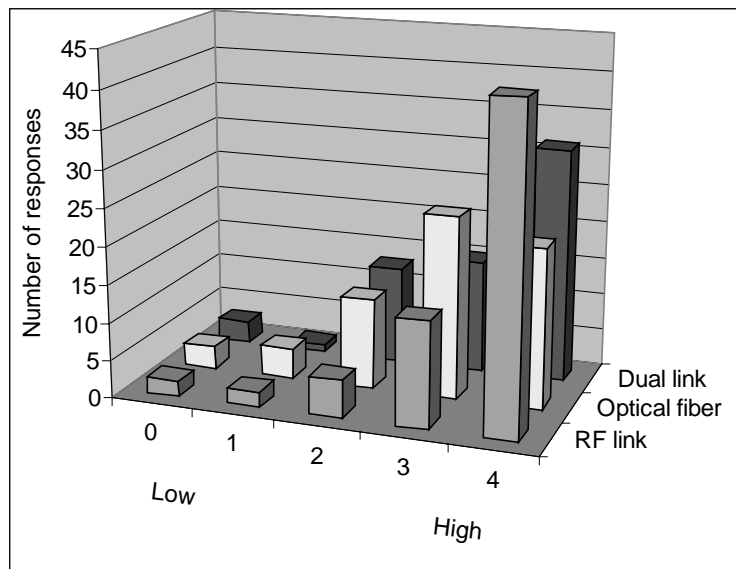
Figure 16 gives similar responses to various indoor terrain features. We see a unique emphasis on the ability to traverse stairs, followed by the capability of travelling over loose rugs and newspapers, and not getting entangled in telephone wires and cables. Though not as strong as the previously mentioned categories, the ability to go under crawlspaces was also deemed important. One survey participant also added the capability to operate in an airplane or bus aisle.



**Figure 16.** Importance of being able to traverse various indoor terrain features.

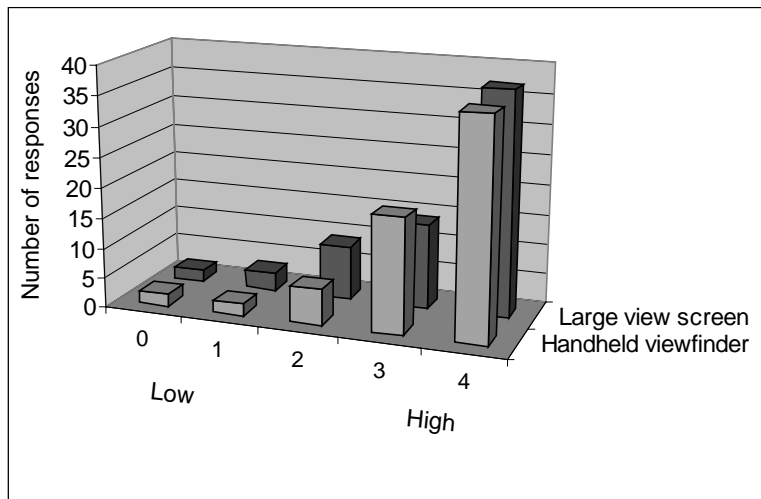
General features:

Figure 17 shows the perceived importance of various remote control and communication links. A radio frequency (RF) link was deemed most important, followed by dual RF/optical-fiber link, with optical fiber alone being last.



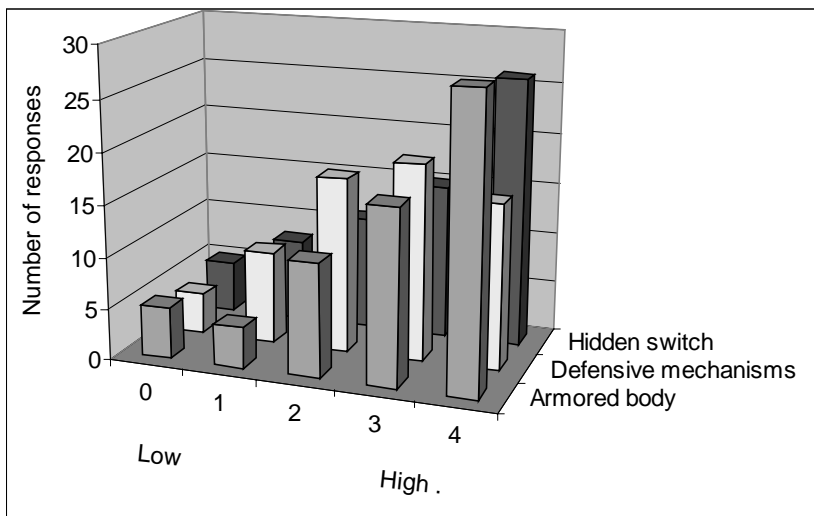
**Figure 17.** Importance of various communication links.

Figure 18 confirms the importance of having a large viewing screen at the command post and a tactical handheld viewfinder that the robot operator can use either in full sunlight or inconspicuously in darkness. The usefulness of having these display modes were identified at the initial meeting with the LASD-SEB.



**Figure 18.** Importance of various video interfaces.

The perceived importance of some self-defense mechanisms is shown in Figure 19. An armored body and hidden deactivation switch were judged to be more critical than keep-away defensive mechanisms (tear gas, electric shocks, etc.), although all three were deemed important.



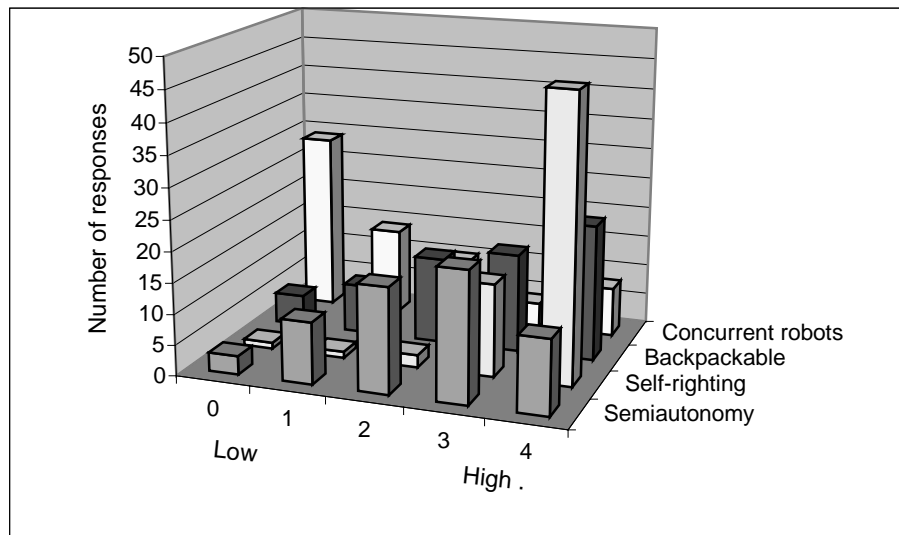
**Figure 19.** Importance of various self-defense mechanisms.

Figure 20 covers more advanced features. Self-righting topped the list, followed by back-packability and semi-autonomy. The ability to operate several robots concurrently did not receive many votes, although the few that voted for it mentioned possible use in scenarios involving large buildings, with one robot acting as a strategically placed sensor and another performing specific tasks.

#### Past experience:

Our survey also asked law enforcement personnel about their experience with the robots they currently use or have used in the past, and any improvement they feel is needed. On the brands of the robots used, two consistently came up: Remotec and Pedasco (although a few respondents could not recall the brand of the robot they used). Although the respondents indicated a success rate of between 50% and 95% using existing robots on non-EOD missions, some areas that could be improved based on their experience were:

- hard-line cable control link (an RF link is desired)
- unreliable RF link
- limited range, speed and battery life
- complicated controls
- robot arm lacking adequate degrees-of-freedom
- mobility over rough terrain (from users of smaller models)
- lack of agility, difficult to control (from users of larger models)



**Figure 20.** Importance of various advanced features.

#### General interests:

The last question we asked was designed to sense the level of interests among law-enforcement personnel in different types of mobile robots. Ground robots were indeed where the most interests lie, followed by a pocket-sized robot that can be thrown or launched through a window. There was little interest in air, underwater or water-surface crafts (Figure 21). A few respondents mentioned liability as the main reason for the low interests in unmanned air vehicles, especially in crowded urban areas.

### **2.3 Differentiation by robotics experience**

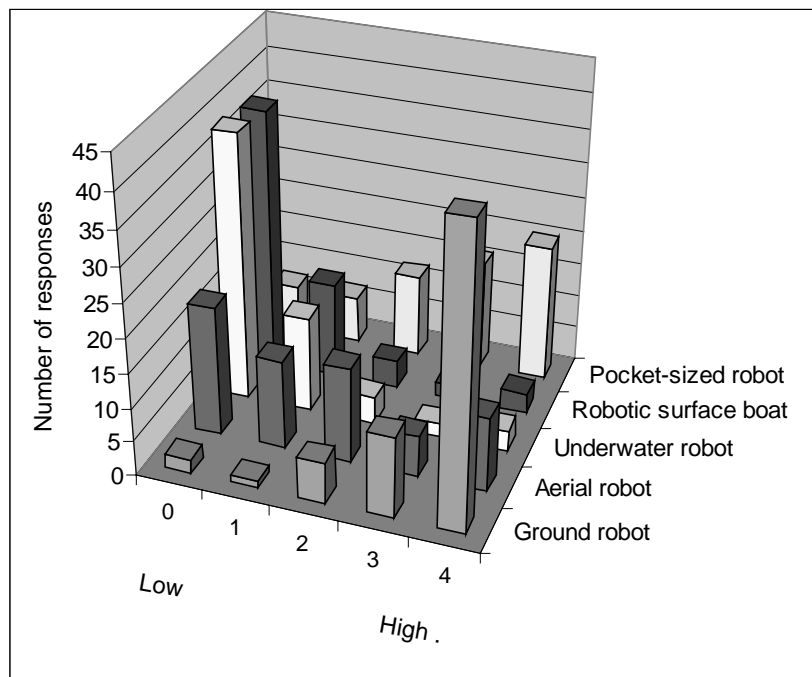
We also separated the data into two sets: one set is composed of respondents reporting no prior experience with robotics, and the second set all others. The tabulation program was run again on the two sets of data. We found no significant difference in most answers, except the group with robotics experience placed more importance on:

- maximum reach for robot (much stronger response for “over 6 feet”)
- longer stand-off distance (“over 500 feet” instead of “250 to 500 feet”)
- lift capability (much stronger response for “over 40 lbs.”)

Appropriately, this group also allowed a higher acquisition cost (20 to 40 thousand dollars vs. under 20 thousand dollars—compare to Figure 14).

Of the general features, the experienced group placed lower importance on semi-autonomy, armor, self-defense and back-packability, and higher emphasis on modularity.

The answer concerning appropriate weight of the robot generated interesting results when differentiated. While the group with no experience overwhelmingly picked 50 to 75 lbs. as most appropriate, the answers from the experienced group were bimodal. There were strong responses both at 25-50 lbs. and 75-100 lbs. Perhaps this reflects the remark from several respondents with robotics background that the robotics needs of the law-enforcement community cannot be satisfied with just one general-purpose robot. There is a requirement both for a heavy, large robot, and a lighter, smaller and more agile robot.



**Figure 21.** Law-enforcement interests in various types of mobile robots.

### 3. DEPARTMENT OF DEFENSE EFFORTS

While there are many commercial robots in existence that may satisfy some of the identified needs of the law enforcement community, a survey of those is outside the scope of this paper. Those interested in examining available commercial platforms are urged to consult sources such as the Unmanned Vehicles Handbook<sup>9</sup> and our Small Robot Technology Database.<sup>10</sup> Here, we discuss only unclassified robotics research and development (R&D) programs by various segments of the Department of Defense, focusing on ground robots.

#### 3.1 JRP

To reduce duplicated ground robotics R&D efforts among various branches of the Department of Defense, in 1989 Congress created the Joint Robotics Program (JRP) under the Office of the Secretary of Defense.<sup>11</sup> The JRP oversees all funding and technology priorities for these efforts, while the services and defense agencies program offices continue to conduct the daily management of these programs. JRP projects range from the more mature EOD systems and vehicle teleoperation kits to advanced software architectures and robotic technology demonstrations.<sup>12</sup> The majority of the ground robotics programs are currently managed by the Unmanned Ground Vehicles/Systems Joint Project Office (UGV/S JPO), a joint Army and Marine Corps organization.<sup>13</sup>

#### 3.2 UGV/S JPO

Most JRP robotics developments of interest to the law-enforcement community currently fall under the management of the UGV/S JPO. They are summarized below.

### MPRS:

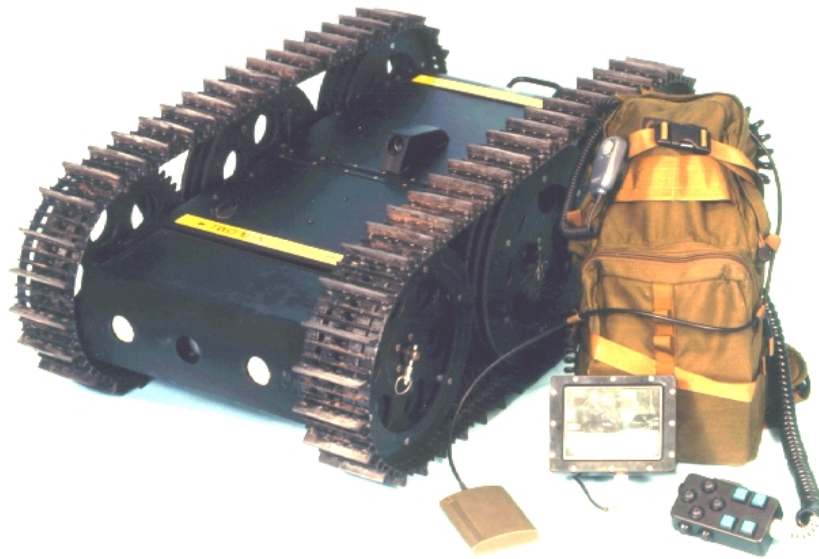
The Man-Portable Robotic System (MPRS), nicknamed URBOT (for urban robot) is a small surveillance robot being developed at SSC San Diego.<sup>14,15</sup> The goal of the program is to develop economical, rugged and lightweight mobile robots for surveillance operation in urban environments. This program bridged the gap between users and technologists by developing prototypes that were field tested by the end users (soldiers). The first-generation prototype was based on a modified Lemming platform from Foster-Miller (Waltham, MA). The second-generation prototypes, of which four were produced, were based on the Foster-Miller Tactical Adjustable Robot. The robot weighs 65 lbs. and is approximately 34" x 20" x 12" in size (see Figure 22). MPRS contributed several significant features and developed several important design rules that might be applicable to law-enforcement robots:

1. An optimized sensor package was developed based on user feedback, including forward-looking video camera, lights, and microphone. The package is mounted in a watertight Sensor Snout that can be tilted up or down as much as 90 degrees, to allow observation of obstacles while breaching obstructions.
2. A driving camera was added on the top of the robot but towards the back of the platform to improve orientation during driving. This allows a forward field-of-view that includes the left and right drive tracks.
3. Instead of self-righting, URBOT is fully invertible (i.e., it can be operated either upside down or rightside up with no preference). An identical driving camera was mounted on the bottom of the robot to be used when the robot is operating upside down, and the video output from the surveillance camera is invertible.
4. It was found that semi-autonomy was more than the soldier required. During operation in hostile environments, the robot must move slowly and stop often, allowing the operator to closely examine the video for anything of tactical importance. Thus a purely teleoperated control strategy was requested by the users, and the more intelligent "reflexive teleoperation" feature was removed from the second-generation robots. Furthermore, the default drive mode was set to "all stop" (i.e., the robot stops when all drive-control buttons on the control pendant were released).
5. A rear-looking video camera with IR capability (eliminating the need for backup lights) was added for backing up the robot from tight spots and tunnels.
6. To satisfy the users' request for a tighter turning radius, the center sprocket on each side was increased in diameter from 10 to 11 inches, providing a "high-center" effect. This also improved maneuverability on most surfaces, including indoor-carpet.
7. A high-speed digital RF video link was implemented, capable of providing real-time video (15 to 20 frames per second). This eliminates ghosting and dropouts associated with an analog link, and consumes much less power. The digital video/audio system is also capable of providing bi-directional audio between the controller and the robot, allowing two-way verbal communication with a remote hostile element.
8. The surveillance camera is equipped with 24X zoom, autofocus and auto-iris functions that can also be controlled via computer (i.e., manually), allowing close-up inspection of targets and optically isolating trip wires and other small objects. The camera also has electronic image stabilization, eliminating frame-to-frame jitter due to mechanical vibration during driving.

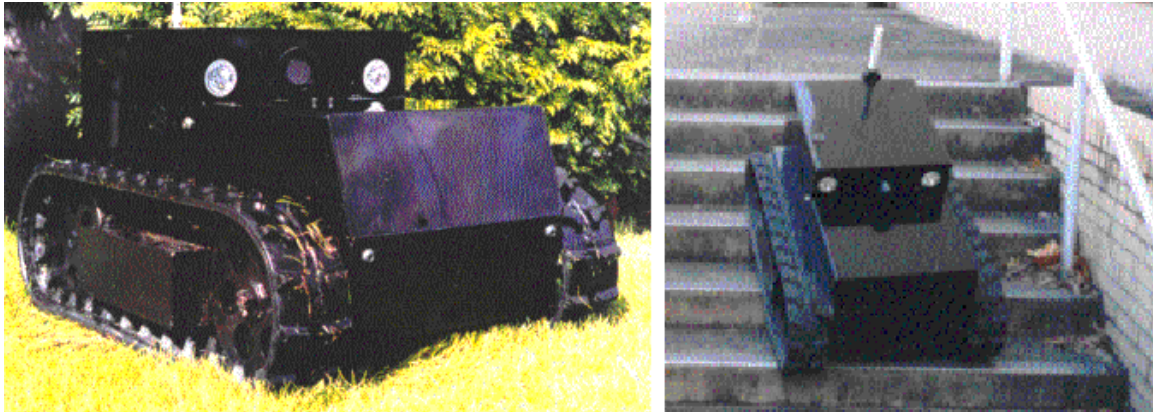
### SPIKE:

The Army Infantry Center at Fort Benning, GA, has evaluated the SPIKE vehicle (produced by II-Tracker, Portland, OR) for use as a reconnaissance and breaching vehicle for Military Operations in Urban Terrain (MOUT). The SPIKE vehicle can be thought of as a miniature tank (425 lbs., 38" x 28.5" x 22.5"—see Figure 23). It has a radio control link with a quarter mile range, and an 8-hp diesel engine that can take the vehicle up to 15 mph.<sup>16</sup> An attractive feature of the SPIKE robot is its ability to breach doors simply by driving through them. Breaching of both hollow-core and solid-core doors, as well as firing of Stingmore mines (Claymore-like mines loaded with hundreds of rubber balls) from the SPIKE vehicle have been successfully conducted at Fort Benning.<sup>17</sup> It also is intimidating enough to potentially be used as a psychological weapon in some situations. (From our conversations with law enforcement officers, we discovered two seldom-mentioned uses for

robots: as a psychological weapon, and to limit liability by showing that positive steps have been taken to ensure public and officer safety.)



**Figure 22.** URBOT (MPRS) with operator control equipment.



**Figure 23.** The SPIKE robot.

#### MATILDA:

The MATILDA is a low-cost (under \$25,000 base price) reconnaissance robot built by Mesa Associates (Madison, AL). It weighs 40 lbs. and measures 26”L x 20”W x 12”H (platform only). Optional attachments include a small trailer (400 lbs. capacity), a manipulator arm, and a remotely detachable breaching mechanism that allows explosive charges to be attached to a door or wall—see Figure 24. UGV/S JPO funded the upgrade of the basic unit (Point Man) to the Urban Warrior version, and acquired 10 units, four of which are being evaluated by the National Guard’s Civil Support Detachment / Weapons of Mass Destruction Teams (CSD-WMD).<sup>18,19</sup> Tests of explosive breaching on simulated walls and doors using the MATILDA robot have been conducted by personnel from the Army Maneuver Support Center (Fort Leonard Wood, MO) at the MOUT Advanced Concept Technology Demonstration (ACTD) in Fort Benning, GA, during the summer of 1999.<sup>20</sup>



**Figure 24.** The MATILDA robot (left) and MATILDA with breaching mechanism (right).

Other robot-mounted weapons and tools:

The UGV/S JPO has been involved in the testing of several robot-mounted less-lethal weapons. In 1999 JPO demonstrated to the US Marine Corps a Foster-Miller device mounted on a SARGE vehicle (Figure 25) that can be loaded with numerous non-lethal weapon canisters such as rubber balls, bean bags, nets, etc.<sup>18,26</sup> (SARGE is a reconnaissance robot originally designed by Sandia National Laboratories and currently produced by SUMMA Technology of Huntsville, AL.) A similar but smaller version of this less-lethal weapon launcher is available for smaller robots such as the Foster-Miller Lemming (see Figure 26).



**Figure 25.** The SARGE robot with Foster-Miller less-lethal weapon launcher.

The Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) has also developed a water cannon that can shoot water and other non-conventional munitions at high velocity. Although its primary use is in EOD applications,

the water cannon was successfully test fired from the Mini-Flail (a 2400-lb. mine-clearing robot built from a John Deere Skip Loader chassis) in breaching exercises at Ft. Leonard Wood in 1999. Both water and steel balls were shot against wood and cinderblock walls.<sup>21</sup> Due to the strong recoil, this device can only be operated from heavier robots.

### 3.3 DARPA

Robotics efforts of the Defense Advanced Research Projects Agency (DARPA) operate outside the umbrella of (but in cooperation with) the JRP. Most DARPA robotics projects involve advanced technology contributing to robotic autonomy or intelligent cooperation between robots. These are currently of low interests to the law-enforcement community, which favors low cost and simple teleoperation. (Among respondents with robotics background, the importance of semi-autonomy rated a 2 on a scale of 0 to 4.) However, some DARPA projects have explored technology areas that may benefit law-enforcement robotics efforts.

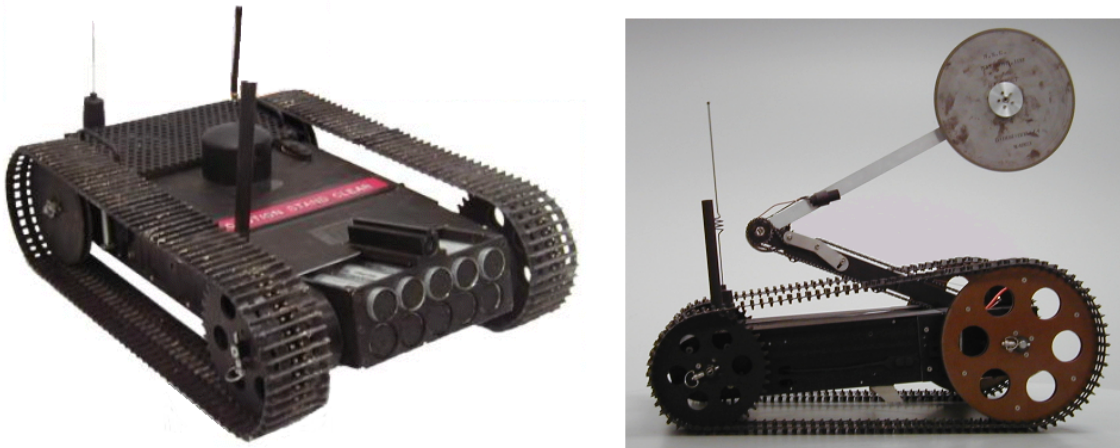
#### TMR:

DARPA's Tactical Mobile Robotics (TMR) program aims to develop new technologies to address some of the most technically challenging aspects of operations in complex terrain.<sup>22,23</sup> This project originated from conceptual requirement analyses done by the Special Operations Forces.<sup>24</sup> Although TMR's focus is on small, semi-autonomous robots, some of the autonomous/semi-autonomous functions being explored are important to all mobile robots operating in hostile environments. These include:

- Self-righting (demonstrated with IS Robotics' Urban Robot)
- Recovery from lost contact or control (by retracing path)

TMR also funded Foster-Miller to develop and demonstrate several robotic mission packages. The following have been demonstrated on a Lemming base:<sup>25,26</sup>

- Launch of snare nets, tear gas, rubber balls and other less-lethal munitions (see Figure 26)
- High-voltage discharge for anti-handling and self-protection
- Non-explosive breaching using a circular saw device (see Figure 26)



**Figure 26.** The Lemming robot with less-lethal weapon launcher (left) and breaching saw (right).

Another element of the TMR program looks at small robots that can be launched from a larger robot or thrown by a human operator (Throwbot class). This type of robot received the second most interest, after conventional ground robots, from the

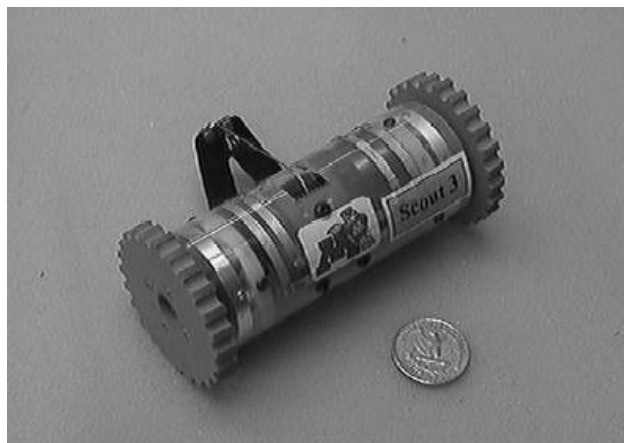
law-enforcement personnel surveyed. TMR funded the Charles Stark Draper Laboratory (Cambridge, MA) to develop several prototypes, and has also been exploring Throwbot concepts using the SuBot (Small Unit Robot—Figure 42), developed with internal funding by the Science Applications International Corporation (Englewood, CO).<sup>27</sup> SuBot is approximately spherical in form, with a 16 cm diameter. It has 2-wheel skid steering with a tail stabilizer. Electronics include a video camera, RF receiver and video transmitter with a 30 m range.



**Figure 42.** SAIC's SuBot.

#### DR:

DARPA's Distributed Robotics (DR) program focuses on advanced technologies supporting large systems of mini and micro robots. However, one project funded under this program, managed by the Center for Distributed Robotics at the University of Minnesota, has potential for applications in law enforcement in the very near future. This project involves small marsupial robots (Ranger) that can carry and launch up to ten even smaller robots (Scout).<sup>28</sup> The Scout vehicles are cylindrical, 40mm in diameter and 110mm long (see Figure 43). They can roll up 20-degree slopes, and hop over 4" obstacles (by winding and releasing a leaf-spring tail). The Scout sensor suite, depending on applications, may include a video camera (fixed or mounted on a retractable pan-and-tilt unit), microphone, vibration sensor, gas sensor, and other sensors. It has a short-range analog RF link, and can be launched through windows, either by the launcher on the Ranger or by a grenade launcher. The robot fits snugly inside a protective covering called a Sabot that absorbs much of the impact during the launch.



**Figure 43.** The Scout robot.

## MUMS II:

Somewhat related to the pocket-sized robot concept, DARPA is funding IS Robotics (Somerville, MA) and Sandia National Laboratories (Albuquerque, NM) to develop a tactical sensor system that can be delivered by a grenade launcher. Named the Micro Unattended Mobility System (MUMS II), the sensor payload is to be deployed using a standard M-203 grenade launcher.<sup>29</sup> To commence operation, the payload is aimed at a target zone on an outside wall between 10 to 50 inches above a window. Upon impact, as the shock absorbing material is collapsing, an explosive nail is driven into the wall to attach the payload package. This method of attachment has been demonstrated on a number of wall surfaces, including reinforced concrete, concrete block, and wood frame. Subsequent to attachment, the sensor system separates from the main package and drops down on a flexible arm until the window is in view. The operator remotely controls the arm to place a miniature camera up against the window glass (to minimize reflections and distortion). The operator would then be able to conduct visual observation of the room interior remotely through an RF link.

Although only in the initial design phase, MUMS II has good potential for use in tactical law-enforcement operations and should be followed closely.

## **4. CORRELATION BETWEEN LAW ENFORCEMENT NEEDS AND DOD EFFORTS**

Table 1 is a matrix matching robotic tasks and features against DOD efforts. The tasks and features selected are those deemed most important or uniquely requested by the law-enforcement personnel surveyed.

From the survey, we saw that the law-enforcement community places the most emphasis on having robots perform the functions of: 1) small-item delivery, 2) passive remote communication, and 3) remote surveillance.

Small-item delivery is typically accomplished by robots with manipulators. Most tele-operated mobile robots are available with a built-in or optional manipulator. Thus the selection criteria are the number of degrees-of-freedom of the manipulator, the ease of control, and the mobility of the platform.

Passive remote communication (i.e., communication requiring no button or switch activation on the remote end) has traditionally been accomplished with analog radios. With the advent of digital CODECs (coder/decoder) implementing the H.32X teleconferencing standards, much more robust communication (video as well as audio) is now available through digital links.

	<b>DOD programs and/or products under evaluation</b>							
<b>LE needs</b>	JPO/ MPRS	JPO/ SPIKE	JPO/ MATILDA	JPO/ Foster- Miller	NAVEOD- TECHDIV	DARPA/ TMR	DARPA/ DR	DARPA/ MUMS II
<b>Tasks</b>								
Surveillance	X	X	X			X	X	X
Delivery of items	Commercially available technology							
Passive communications	Commercially available technology							
Tunnel reconnaissance	X							
<b>Features</b>								
Stair climbing						X		
Robust RF link	X					X		
Longer battery life	Current research area, not specific to robotics							
Low cost			X					
Less-lethal weapons		X		X	X	X		
<b>Robot types</b>								
Large robots		X						
Small robots	X		X			X	X	
Pocket-sized robot						X	X	X

**Table 1.** Correlation between law-enforcement needs and DOD efforts.

Remote surveillance is an active technology development area where the DOD has much to offer. Projects to watch for contributions in this area include the JPO's MPRS and DARPA's TMR and MUMS.

The capability for reconnaissance of tunnels and storm drains at U.S. ports of entry was requested by a member of the Border Patrol. This application is being specifically addressed by the MPRS program and should be directly transferable.

On the issue of robot mobility, the ability to traverse rubble and stairs was considered most important, as well as a self-righting capability. These capabilities are being addressed by the MPRS program (near-term) and the TMR program (long-term).

Law enforcement personnel with robotics experience indicated dislike for both hard-line control links and unreliable RF links. While both the MPRS and TMR programs are addressing this issue with more reliable digital RF links and relays, continuous high-bandwidth non-line-of-sight communication is a significant problem that still needs to be solved.<sup>23</sup>

Similarly, extending mission duration (through improved energy sources) was noted as a primary concern. There are current research programs (not related to robotics) at DARPA and various universities addressing this issue.

Cost is often a major consideration with law enforcement agencies. The low-cost MATILDA line of robots was developed mainly to address this issue, and is being evaluated by the JPO.

Robot-mounted less-lethal weapons were not ranked high on the priority list, but are included here because this is an active topic in DOD robotics. The JPO and the Army investigated several less-lethal weapon launchers, and DARPA funded Foster-Miller's development of several mission packages including less-lethal weapons.

From the survey results and discussions with law enforcement personnel, it became evident to us that there will be no single robot that will meet all the demands of law enforcement beyond EOD. For example, a fairly large robot would be required to traverse rubble and other rough terrain, be able to handle a heavy payload, and act as a psychological weapon. The SPIKE vehicle, currently being evaluated by the Army, or one of the larger models of existing EOD robots may be able to assume this role. However, there is also a need for a smaller robot that is more agile and can be more easily maneuvered in tight spaces for surveillance and remote communication purposes. Both the TMR and MPRS programs are looking at this type of application. On an even smaller scale, DARPA's TMR, DR, and MUMS programs are investigating pocket-sized robots that can be thrown, launched by a grenade launcher, or carried by another robot. This type of robot has also received interests from the law enforcement community.

While we have included in this report DOD programs that could contribute to law-enforcement robotics needs beyond EOD, a complete survey of all robotics-related technologies must include on going university research as well as commercial developments and products. Assimilating this data in a meaningful fashion represents an enormous challenge, due to the broad spectrum of disciplines supporting robotics and the explosive growth within many of these areas. Fortunately, a technology assessment of this type has already been started. The JRP has recently tasked SSC San Diego to develop and maintain a comprehensive Mobile Robot Technology Database, which will be available for access by all government agencies. This database will expand upon the currently available Small Robot Technology Database<sup>10</sup> and will include platforms of all sizes and the associated supporting technologies.

## **5. RECOMMENDATION**

We have conducted a survey that identified the general robotics needs of the law enforcement community. This, together with our survey of DOD robotics efforts and the upcoming availability of the Mobile Robot Technology Database, should provide a starting point for a Department of Justice (DOJ) program for the development of law-enforcement robots beyond EOD. Since we have concluded that no single robot will satisfy the full spectrum of desired functionality, and it is too cost-prohibitive to develop many application-specific robots, we recommend that the DOJ pursue the development of two classes of robot, separated by size. Each robot should be modular, with application-specific mission packages or tool sets that can be tailored to the needs of a specific user.

The most important criterion for a successful program is producing an end product that the user will use and appreciate. Closing the loop with the user should therefore be the number one priority throughout the design and development process. This is often complicated by three factors: 1) the developing engineers typically do not know much about what the user does, 2) the users do not know much about what the technology can and cannot do, and so 3) the users do not know what to ask for in terms of realistic functional capabilities. This report is an initial attempt at bridging this gap. However, several more iterations of information exchange between the users and the developers are needed during the execution of a successful acquisition program. We therefore suggest that the development of each of the suggested robot classes follow a user-centric phased rapid-prototyping approach that has resulted in several successful robotics development programs at SSC San Diego.<sup>15,30</sup> This procedure involves:

- Interviewing the intended user face-to-face for specific applications, where requirements are further quantified.
- Translating these requirements into needed system functionalities.
- Matching these functionalities to technological needs required to achieve successful implementation.
- Breaking these technological needs down into three categories:
  - 1) Those that currently exist as state of the art.
  - 2) Those that are likely to come along within the development schedule.
  - 3) Those that are project specific, unlikely to be addressed by industry or academia, and therefore must be developed as part of the program.
- Preparing a preliminary specification for a baseline configuration and presenting to the appropriate users for feedback.
- Proposing a first-generation prototype design to the users for further feedback.
- Prototyping a revised design, then giving the prototyped unit to the users for extensive hands-on evaluation.
- Implementing a final design based on subsequent lessons learned in the real world.

To keep cost to a minimum, any design should leverage existing robotic platforms as well as other on-going robotics projects. It should also be modular, with an eye towards simple expansion to include additional capabilities at a later date. For fairly simplistic initial applications, an organization experienced in robotics development should be able to accomplish the entire process in a 12 to 14-month time frame.

Finally, since law-enforcement and military applications very often overlap, we recommend that the DOJ continue to maintain close liaison with both DARPA and the JRP, and obtain input from the JRP in the technology survey and assessment, source selection, and development of robotics assets.

## **DISCLAIMER**

With respect to information provided in this document, neither the United States Government nor any of its employees make any warranty, expressed or implied, including but not limited to the warranties of merchantability and fitness for a particular purpose. Further, neither the United States Government nor any of its employees assume any legal liability for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed.

Reference herein to any specific commercial products, processes, or services by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government. The information and statements contained in this document shall not be used for the purpose of advertising, or to imply the endorsement or recommendation of the United States Government.

## **REFERENCES**

1. *Final Report on Law Enforcement EOD Robot* (TSWG Task T-150B2), Battelle, Columbus, OH, for Office of Special Technology, Fort Washington, MD, October 1999.
2. *Robotics for Law Enforcement: Beyond Explosive Ordnance Disposal*, Technical Report 1839, Space and Naval Warfare Systems Center, San Diego, CA, October 2000.
3. *Survey on Law Enforcement Needs for Non-EOD Robots*, Space and Naval Warfare Systems Center, San Diego, CA, May 2000, URL: <http://www.spawar.navy.mil/robots/lesurvey/>.

4. National Law Enforcement and Corrections Technology Center, URL: <http://www.nlectc.org/links/lelinks.html>.
5. Officer.com, URL: <http://www.officer.com>.
6. Washington D.C. Metropolitan Police Department links, URL: <http://www.mpdcc.org/English/About/LELinks.htm>.
7. New York City Police Department links, URL: <http://www.ci.nyc.ny.us/html/nypd/html/sites.html>.
8. National Tactical Officers Association, URL: <http://www.ntoa.org/>.
9. *Unmanned Vehicles Handbook*, Burnham, Bucks, England: The Shephard's Press, 2000.
10. *Small Robot Technology Database*, Space and Naval Warfare Systems Center, San Diego, URL: <http://robot.spawar.navy.mil/mprs/Home.asp>.
11. "Program History," Joint Robotics Program, Office of the Secretary of Defense, URL: <http://www.jointrobotics.com/History/index.html>.
12. "Joint Robotics Program Master Plan, FY2000," Joint Robotics Program, Office of the Secretary of Defense, URL: <http://www.jointrobotics.com/WebDocs/2000MasterPlan/JRP%20Master%20Plan%202000.pdf>.
13. Unmanned Ground Vehicles/Systems Joint Project Office (UGV/S JPO), Redstone Arsenal, Huntsville, AL, URL: <http://www.redstone.army.mil/ugvsjpo/>.
14. Man-Portable Robotic System, URL: <http://www.spawar.navy.mil/robots/land/mprs/mprs.html>.
15. Laird, R.T., et al., "Issues in Vehicle Teleoperation for Tunnel and Sewer Reconnaissance," IEEE Int. Conf. on Robotics and Automation (ICRA2000), San Francisco, CA, April 2000 (URL: <http://www.spawar.navy.mil/robots/pubs/icra2000b.pdf>)
16. Telephone and electronic correspondence with Mr. George Osgood, II-Tracker, Portland, OR, 8 August 2000.
17. Telephone interview with Mr. Irving (Rod) Rodriguez, Directorate of Combat Development, US Army Infantry Center, Ft. Benning, GA, 21 August, 2000.
18. Interview and follow-up electronic correspondence with Mr. Keith Anderson, UGV/S JPO, Huntsville, AL, 1 June - 16 August 2000.
19. Telephone and electronic correspondence with Mr. Don Jones, Mesa Associates, Madison, AL, 10 August 2000.
20. Telephone interview with Sgt. Bill Rodstad, Department of Training and Development, US Army Maneuver Support Center, Ft. Leonard Wood, MO, 21 August 2000.
21. Telephone interview with Mr. Earl Scroggins, Naval Explosive Ordnance Disposal Technology Division, Indian Head, MD, August 24, 2000.
22. Blitch, LTC J., "Tactical Mobile Robots for Complex Urban Environments," SPIE Conf. on Mobile Robots XIV, Boston, MA, September 1999, SPIE Vol. 3838, pp. 116-128.
23. Krotkov, Eric and John Blitch, "The Defense Advanced Research Projects Agency (DARPA) Tactical Mobile Robotics Program," *The International Journal of Robotics Research*, Vol. 18, No. 7, July 1999.
24. Blitch, LTC J.G., et al., "SOMROPE I: A Simulation Based Risk Analysis for Robot Assisted Special Reconnaissance," Proc. IASTED Int. Conf.: Applied Modeling and Simulation, Honolulu, HI, August 1998, pp. 285-290.
25. Interview with Dr. Douglas Gage, SSC San Diego (now with DARPA ITO), 2 May & 21 August 2000.
26. Telephone and electronic correspondence with Mr. Arnis Mangolds, Foster-Miller Inc., Waltham, MA, 17-18 August 2000.
27. Spofford, John, et al., "Vision-guided Heterogeneous Mobile Robot Docking," *Sensor Fusion and Decentralized Control in Robotic Systems II*, SPIE Proc. 3839, Boston, MA, September 1999.
28. Hougen, Dean F., "A Miniature Robotic System for Reconnaissance and Surveillance," IEEE International Conference on Robotics and Automation, San Francisco, CA, April 2000, pp. 501-507.
29. Sword, Lee, "Micro-Unattended Mobility System for Grenade Launcher Deployed Sensors (MUMS II)," SPIE Vol. 4040: *Unattended Ground Sensor Technologies and Applications II*, Orlando, Florida, 24-28 April 2000.
30. Everett, H.R., et al., "Technical Development Strategy for the Mobile Detection Assessment Response System—Interior (MDARS-I)," Technical Note 1776, Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA, August 1996.